

# Ceeable Visual Field Analyzer (CVFA™) for the Portable, Comprehensive, and Tele-medical Assessment of Visual Performance over Time in Warfighters, Pilots, Veterans, and Civilians

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## ABSTRACT

We introduce a portable, easy-to-use, worldwide accessible (i.e., web-based), and comprehensive tele-medical visual performance assessment system – the Ceeable Visual Field Analyzer (CVFA™) – for warfighters, pilots, veterans, and civilians to: (1) Accurately and rapidly assess visual performance; (2) characterize visual performance and ocular conditions; and (3) detect the onset of ocular conditions to allow for timely countermeasures as well as patient follow-up over time. CVFA has been shown to be effective in multiple clinical studies. The technology is rapid (< 5 minutes per eye), easy (use of touchscreen), accurate (spatial resolution < 1 degree), non-invasive, and comprehensive. The system automatically characterizes visual field defects in real time to generate new diagnostic insight. The visual performance assessment system is readily adaptable to traditional clinical and non-clinical settings (e.g., in forward operating bases in the theatre). It is capable of rapidly assessing conditions affecting the visual performance of warfighters in the field, allowing for triage and timely application of therapeutic countermeasures. The enabling technologies are a low-cost tablet computer and Internet connection. Ceeable is deploying the technology on a global basis to patients who will benefit from monitoring changes in visual function.

**Keywords:** Warfighter, pilot, veteran, civilian, visual performance, visual field, contrast sensitivity, mobile, portable, touchscreen, field-deployable, telemedicine, worldwide accessible

## 1. INTRODUCTION

Vision is the primary sense used by warfighters, pilots, veterans, and civilians, and visual information is essential during all phases of military operations. Visual performance risks during military operations include possible corneal, lens and retinal damage from military combat, UV exposure, retinal thermal damage from excessive visible light and IR/laser exposure, intracranial and/or intraocular hypertension such as from head trauma and traumatic brain injury (TBI) (e.g., due to explosions), and toxic environmental poisoning. For TBI in particular, according to the literature, 20-40% of people with brain injury experience related vision disorders. However, the exact prevalence is not known.<sup>1,2</sup> The detection and assessment of TBI is crucial to allow for traumatic brain injury care management to commence.

On a global scale, i.e., worldwide, the general (elderly) population is increasingly affected by major chronic diseases of the eye. The Lighthouse International information webpage on “Prevalence of Vision Impairment”<sup>3</sup> provides some worldwide estimates that are paraphrased in the following: *Over 285 million people in the world are visually impaired, of whom 39 million are blind and 246 million have moderate to severe visual impairment (World Health Organization (WHO), 2011). It is predicted that without extra interventions, these numbers will rise to 75 million blind and 200 million visually impaired by the year 2020 (WHO, 2010). According to the World Health Organization (2010), cataract is the leading cause of blindness in the world (47.8%). However, it is treatable in a straightforward manner through surgery, i.e., replacement of the crystalline lens with an intraocular lens. It is estimated that 67 million people worldwide have glaucoma, up from 60.5 million worldwide in 2010.<sup>4</sup> This number is expected to rise to about 80 million people worldwide by 2020.<sup>4</sup> As such, glaucoma is the 2nd leading cause of blindness (12.3%) in the world (WHO, 2006). In contrast to cataract, glaucoma is not curable. At best, the progression of visual field loss due to glaucoma can be stopped or delayed. Age-related macular degeneration, the 3rd leading cause of blindness (8.7%), affects 25-30 million*

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people worldwide in some form (AMD Alliance International, 2002). Similar to glaucoma, AMD is generally not curable. Worldwide, 2.5 million people experience vision loss due to diabetic retinopathy (4.8%; International Diabetes Federation, 2007).

Given all the above, early detection of visual performance impairment (both acute and chronic) and blinding diseases is essential as it may allow for actual treatment to avert or at least significantly delay the onset or progression of vision loss. Moreover, access to even adequate ophthalmic healthcare is often challenging if not impossible for people who are geographically dispersed (e.g., rural populations), or who operate/live in austere environments (e.g., third world, natural disaster areas, military environments such as forward operating bases). Therefore, the development and deployment of a portable, easy-to-use, integrated, worldwide accessible, and comprehensive visual performance assessment system is indicated for:

- (1) Accurately and rapidly assessing visual performance;
- (2) Characterizing and diagnosing visual performance and ocular conditions;
- (3) Detecting the onset of ocular conditions to allow for timely countermeasures as well as patient follow-up over time.

## 2. UNDERLYING PSYCHOPHYSICAL METHOD

For the visual performance assessment of warfighters, pilots, veterans, and civilians we employ the *3D Computer-automated Threshold Amsler Grid (3D-CTAG)* test.<sup>5</sup> With one eye covered, subjects are positioned in front of a touch-sensitive computer screen (Fig. 1) or tablet (e.g., iPad; Fig. 2) on a head-chin rest. While focusing on a central fixation marker, they trace with their finger either areas of an Amsler grid (Fig. 2) that are missing from their field of vision when screening for scotomas (Fig. 3, left), or areas that are distorted when testing for metamorphopsia (Fig. 3, right). While performing the test, subjects wear their respective refractive corrections (e.g., glasses or contact lenses) if need be.



Figure 1. Standard configuration of visual performance assessment system consisting of touchscreen and head-chin rest.

The Amsler grid<sup>6,7</sup> was introduced in 1947. It represents a standard means of evaluating the central vision surrounding the fovea, i.e., central 10 degrees radially from fixation. The Amsler grid is capable of identifying absolute visual field defects (i.e., absolute scotomas) by using an absolute contrast target, i.e., a black grid on a white background. However, the Amsler grid, as originally introduced, is not sensitive enough to detect subtle visual field defects such as relative scotomas. As opposed to absolute scotomas, relative scotomas change in size and shape as a function of contrast, and often indicate the onset of a disease. To overcome this apparent deficiency, Amsler grids at various degrees of contrast are presented by repeating the test at different grayscale levels. This results in probing the hill-of-vision (Fig. 4) at different altitudes, thus allowing the detection of relative scotomas. The resulting three-dimensional (3D) data represent the measured retinal contrast sensitivity (i.e., the 3<sup>rd</sup> dimension) across the tested visual field. Following each test, a 3D depiction of the central hill-of-vision (Fig. 5, left), a topographical contour map (i.e., the isopters; Fig. 5, left), the area of visual field loss as a function of Amsler grid contrast (Fig. 5, right), and a comprehensive visual field and scotoma characterization and classification<sup>8-10</sup> are automatically generated and displayed onscreen in near real-time.

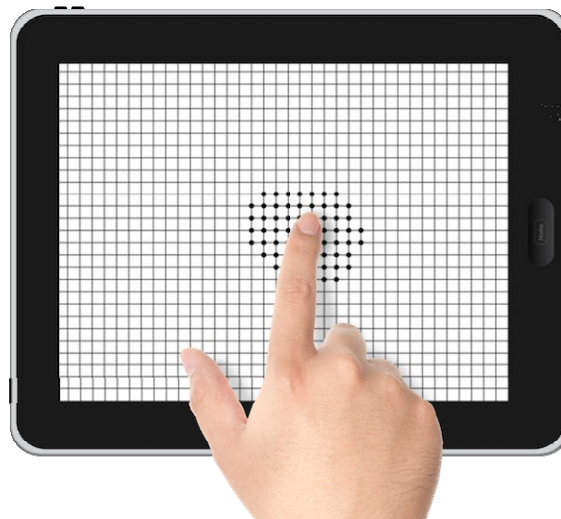


Figure 2. Tablet configuration of visual performance assessment system. The subject outlines with their finger onscreen the areas of an Amsler grid that are either missing or distorted.

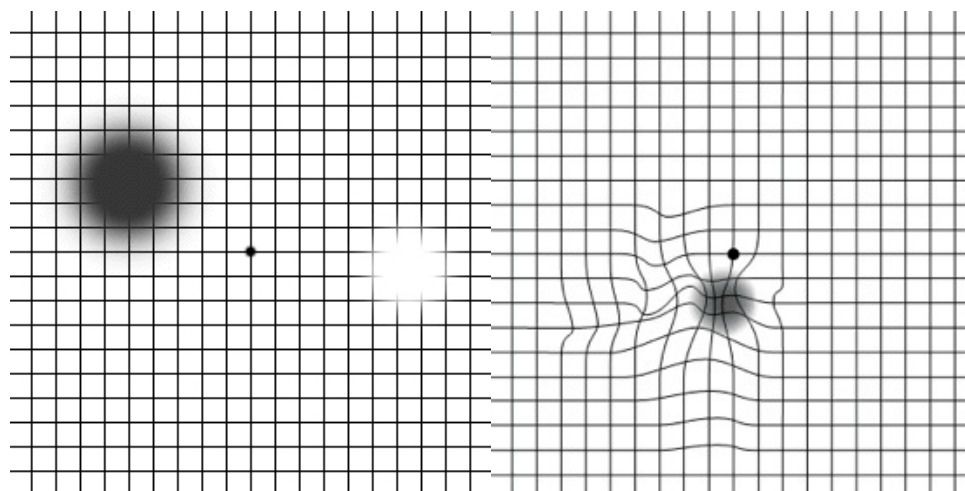


Figure 3. *Left:* Manifestation of scotomas (i.e., visual field defects, exhibited by missing grid lines) on an Amsler grid. *Right:* Manifestation of metamorphopsia (i.e., grid distortions) on an Amsler grid.

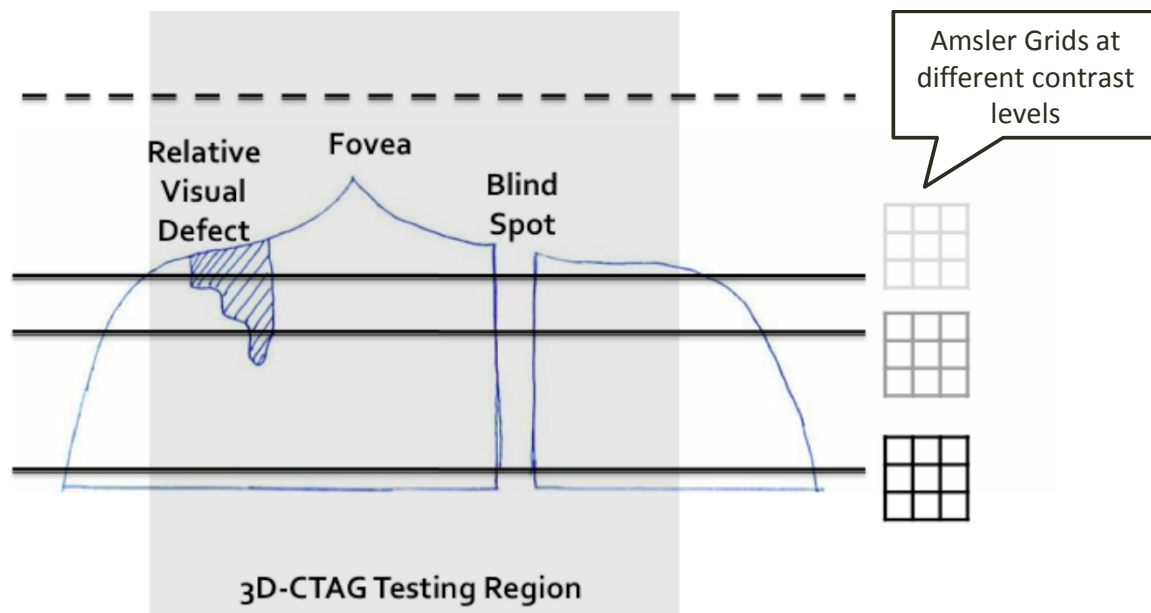


Figure 4. Depiction of hill-of-vision in a vertical cut. The area of sharpest vision is the fovea. The contrast-sensitivity of the visual field drops towards the periphery, i.e., towards higher eccentricities. Amsler grids at different contrast levels probe the hill-of-vision at different altitudes, thus allowing the detection of relative visual field defects, i.e., scotomas.

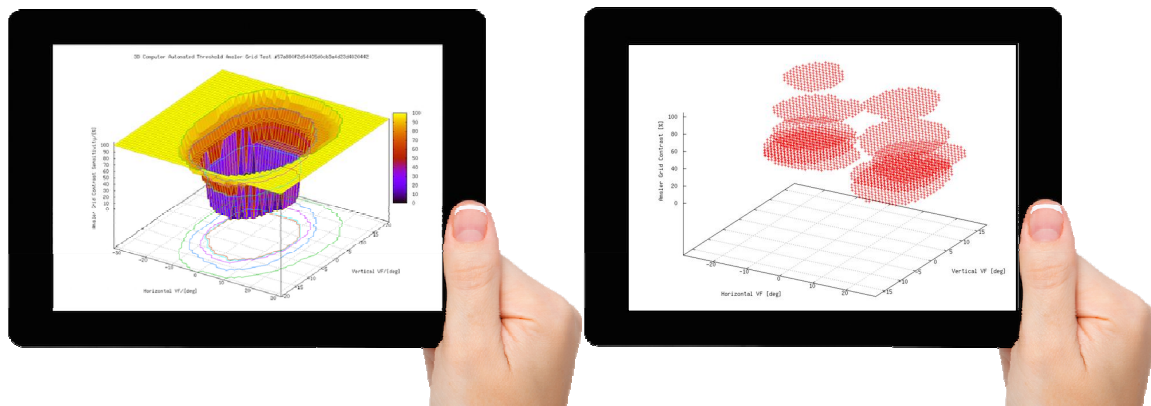


Figure 5. CVFA™ test results: central hill-of-vision (*left*), topographical contour map, i.e., isopters (*left*), and areas of visual field loss as a function of Amsler grid contrast (*right*).

### 3. RESULTS

With support of the Department of Defense Peer Reviewed Medical Research Program (PRMRP) Army Research Office Grant W81XWH-09-1-0266, we have developed a Web-based, portable (i.e., iPad or tablet), tele-medical, and comprehensive visual field test and characterization system - termed *Ceeable Visual Field Analyzer (CVFA™)*<sup>11,12</sup> - to rapidly assess the visual performance of warfighters, veterans, and civilians worldwide via the Internet (Fig. 2). This visual performance assessment system is currently at Technological Readiness Level (TRL) 7. TRL is a metric used by military and space agencies to measure readiness status. CVFA™ is based on the 3D Computer-automated Threshold Amsler Grid (3D-CTAG) test.<sup>5</sup> In multiple clinical studies,<sup>13-20</sup> 3D-CTAG has proven to be innovative, successful, and superior to state-of-the-art standard automated perimetry (e.g., Humphrey Visual Field Analyzer (Fig. 6), i.e., the “Gold Standard”). 3D-CTAG allows for fast (i.e., < 5 minutes per eye), easy (i.e., use of touchscreen/tablet; Figs. 1 and 2),

accurate (i.e., spatial resolution  $< 1$  degree of visual field), non-invasive, and comprehensive visual field testing in 3D. All visual performance assessment test results are stored in a Postgres relational database for re-access and annotation purposes,<sup>9,21</sup> thus allowing for physician remote-access.

For subsequent analysis, CVFA™ is also equipped with an automated and integrated analysis and characterization system.<sup>8-10</sup> The auto-characterization system analyzes in real time the visual field test data and objectively characterizes the occurring vision impairments, such as absolute and relative visual field defects (i.e., absolute and relative scotomas), as well as metamorphopsia. It generates new diagnostic insight through objectively derived parameters<sup>8-10</sup> that characterize the visual field test results, thus enabling or facilitating triage and timely application of therapeutic countermeasures, and offering modern computer-assisted diagnosis in both medicine and telemedicine in military settings (e.g., forward operating bases) and beyond.



Figure 6. Zeiss-Humphrey Visual Field Analyzer – the current “Gold Standard” in visual field testing.

#### 4. DISCUSSION

In the following we list some of the major advantages of CVFA™ over state-of-the-art standard automated perimetry devices (e.g., Zeiss-Humphrey Visual Field Analyzer; Fig. 6):

- **3D vs 2D:** CVFA™ provides unique insight into visual field defects (i.e., scotomas) and metamorphopsia by measuring and displaying the hill-of-vision in 3D as opposed to 2D (Figs. 5 and 7).
- **Superior Resolution:** CVFA™ test results have a spatial resolution that is at least 36 times greater (for a 1 degree Amsler grid spacing) than standard automated perimetry devices (Figs. 1 and 2). It should be noted that microperimetry can achieve high spatial resolution, but usually only for a predetermined (i.e., by the physician) retinal area with a custom-grid and in a non-automatic fashion.
- **Shorter Examination Time:** CVFA™ tests are performed quickly ( $< 4$  min. per eye), making frequent retesting feasible for patient follow-up over time.
- **Early Detection:** In clinical tests CVFA™ was able to detect the early onset of macular degeneration and glaucoma before they were apparent in standard automated perimetry devices.<sup>14,15</sup> Additionally, CVFA™ is



capable of monitoring central visual field loss, e.g., due to macular degeneration, in contrast to conventional visual field tests because of the possibility of peripheral/eccentric fixation markers.<sup>10</sup>

- **Compact Size:** Standard perimetry devices are bulky and heavy (> 50 lbs; Fig. 1); CVFA™ consists of only a tablet (e.g., iPad; Fig. 2) and a head-chin rest.
- **Easily Deployable:** CVFA™ is a truly tele-medical application, i.e., results can be interpreted remotely via the Internet. It only requires a tablet and an Internet connection to operate. As opposed to bulky standard perimetry devices, it is easily deployable anywhere, including Military Health System (MHS) facilities and even forward operating bases. In the event that an Internet-connection is severely bandwidth-limited, or, for security reasons, non-existent, CVFA™ can also be operated in a store-and-forward mode, which transmits the examination data once an Internet-connection can be safely reestablished. Alternatively, CVFA™ can be operated in a self-contained model locally on a tablet or touchscreen computer. Here both the database for the examination data and the automated and integrated analysis and characterization system<sup>8-10</sup> would be residing on the same tablet or touchscreen computer, or, connected via Intra-net to a local server.
- **Lower Cost:** CVFA™ operates on low cost commodity tablets (e.g., iPad or Android tablets) as opposed to standard automated perimetry devices that can cost more than \$20K.

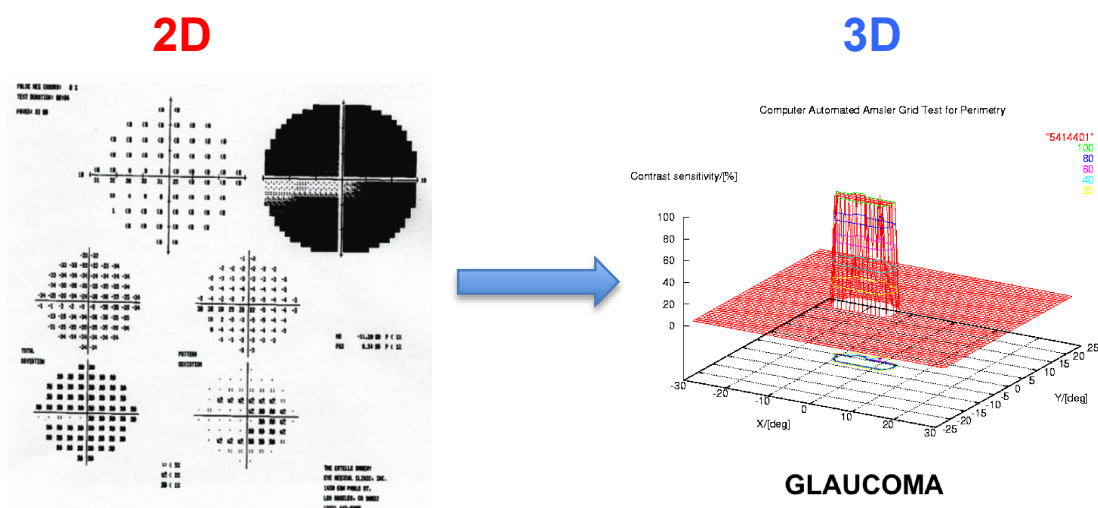


Figure 7. *Left:* Standard presentation of visual field exams in two dimensions (here: severe case of glaucoma) as produced by standard automated perimetry devices such as the Zeiss-Humphrey Visual Field Analyzer – the current “Gold-Standard” in visual field testing. *Right:* Three-dimensional depiction of the same glaucomatous visual field defect as delivered by the Ceeable Visual Field Analyzer CVFA™, allowing for enhanced diagnostic insight, such as shape, extent, and contrast-sensitivity slope of visual field defects.

## 5. CONCLUSIONS & OUTLOOK

The Ceeable Visual Field Analyzer (CVFA™) is readily adaptable to traditional clinical and non-clinical settings (e.g., in forward operating bases in the theatre). The enabling technologies are a low-cost tablet computer and an Internet connection. In the (necessary) absence of an Internet-connection, CVFA™ can also be operated in store-and-forward mode, or in a self-contained Intra-net mode. Critically, its clinically demonstrated capability of early detection of glaucoma and macular degeneration allows for timely countermeasures to prevent irreversible blindness. As such it has the potential to change the standard of care in visual field examinations in particular and visual performance assessment in general.

The visual performance assessment system provides medical support personnel, both in hospitals and in the field, with a non-invasive, accurate, sensitive, and rapid visual performance assessment, a database for patient data, and sophisticated

real-time analysis and characterization of vision impairments. In particular, the system is suitable for rapidly assessing conditions affecting the visual performance of warfighters in the field (e.g., forward operating bases in the theatre), allowing for triage and timely application of therapeutic countermeasures.

Moreover, CVFA™ has attracted interest in its potential use on the International Space Station (ISS)<sup>9,10,22-24</sup> especially with respect to investigating and mitigating the Visual Impairment/Intracranial Pressure (VIIP) Syndrome that has been identified as the top health risk associated with long-duration space travel: elevated intracranial pressure impacts the visual health of astronauts both during long-duration space travel, potentially causing an impact to the mission, and after flight, causing significant (irreversible) morbidity.

Thanks to the worldwide accessibility of the Internet, CVFA™ permits testing of patients on a local to regional to global scale, and offers a promising perspective towards modern computer-assisted diagnosis in medicine and telemedicine in military settings and beyond. CVFA™ may also hold promise in the detection and assessment of TBI and concussions, as both can be associated with related vision disorders.

## 6. ACKNOWLEDGEMENTS

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